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(19)

(72) Inventor ALAN FRANCIS FINCH

(54) MULTI-LOUDSPEAKER ASSEMBLIES FOR STEREOPHONIC SOUND REPRODUCTION

(71) We, PHILLIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to multi-loudspeaker assemblies for producing stereophonic (binaural) sound from two stereophonic audio-frequency signal channels. The signal channels are generally referred to as the 'A and B' or 'left and right' channels.

It is known to provide a plurality of loudspeakers on one face of an elongate housing in order to give a "spread" of sound at a high volume level. Such assemblies are generally referred to as "column loudspeakers". In order to improve the sound quality, or "fidelity", over the audio-frequency range, it is common practice to employ a mixture of loudspeakers having different frequency responses. Thus for a medium quality system, one or more loudspeakers may be provided which predominantly respond to a frequency range covering the low-frequency ("bass") and mid-range frequencies of the audio spectrum, and a further one or more loudspeakers may be provided which predominantly respond to a frequency range covering the higher frequencies ("treble") of the audio spectrum.

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To achieve optimum efficiency and minimum distortion in the system, a so-called cross-over filter network is provided which splits the input signal into frequency bands such that each loudspeaker is fed with signals having a frequency band corresponding to its response band. The frequency or frequencies where the frequency response characteristics of the filtered bands cross are referred to as the cross-over frequencies of the network and each cross-over filter is designed to provide the particular cross-over frequencies required for the system concerned. Thus in a system using only two types of loudspeaker the cross-over frequency may be anything from about 400 Hz to 4000 Hz depending upon the loudspeakers used. In a system using three types of speakers (woofer, squawker, and tweeter) the lower cross-over frequency is typically of the order of 300 Hz to 500 Hz and the upper cross-over frequency is typically in the range 4000 Hz to 6000 Hz.

Housings, or 'enclosures', for the loudspeakers usually fall into two categories; the vented (or 'reflex') enclosure and the sealed enclosure ('infinite baffle').

When a vent is cut in the wall of a sealed enclosure, the enclosure behaves as a resonating system due to the behaviour of the air near the vent. The resonance frequency of the enclosure depends upon the volume of the enclosure and on the dimensions of the vent. By matching this resonance frequency to that of the loudspeaker, the correct acoustic loading is ap-

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It is known to provide a plurality of loudspeakers on one face of an elongate housing in order to give a "spread" of sound at a high volume level. Such assemblies are generally referred to as "column loudspeakers". In order to improve the sound quality, or "fidelity", over the audio-frequency range, it is common practice to employ a mixture of loudspeakers having different frequency responses. Thus for a medium quality system, one or more loudspeakers may be provided which predominantly respond to a frequency range covering the low-frequency ("bass") and mid-range frequencies of the audio spectrum, and a further one or more loudspeakers may be provided which predominantly respond to a frequency range covering the higher frequencies ("treble") of the audio spectrum.

In a high quality system, three types of loudspeakers may be used, namely a bass loudspeaker (or "woofer"), a mid range loudspeaker ("squawker") and a treble loudspeaker ("tweeter"). Each type of loudspeaker is designed to respond predominantly to the frequencies in its range by providing its moving system with one or more natural resonances within its particular frequency range.

To achieve optimum efficiency and minimum distortion in the system, a so-called cross-over filter network is provided which splits the input signal into frequency bands such that each loudspeaker is fed with signals having a frequency band corresponding to its response band. The frequency or frequencies where the frequency response characteristics of the filtered bands cross are referred to as the cross-over frequencies of the network and each cross-over filter is designed to provide the particular cross-over frequencies required for the system concerned. Thus in a system using only two types of loudspeaker the cross-over frequency may be anything from about 400 Hz to 4000 Hz depending upon the loudspeakers used. In a system using three types of speakers (woofer, squawker, and tweeter) the lower cross-over frequency is typically of the order of 300 Hz to 500 Hz and the upper cross-over frequency is typically in the range 4000 Hz to 6000 Hz.

Housings, or 'enclosures', for the loudspeakers usually fall into two categories; the vented (or 'reflex') enclosure and the sealed enclosure ('infinite baffle').

When a vent is cut in the wall of a sealed enclosure, the enclosure behaves as a resonating system due to the behaviour of the air near the vent. The resonance frequency of the enclosure depends upon the volume of the enclosure and on the dimensions of the vent. By matching this resonance frequency to that of the loudspeaker, the correct acoustic loading is applied to the loudspeaker cone. In systems where different types of loudspeaker are employed, the loudspeaker concerned is that which covers the lower audio frequencies (e.g. a woofer). The bass reproduction qualities of the reflex enclosure are very good indeed but, to provide correct matching at the very low bass

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frequencies (typically in the order of 40-50 Hz), the enclosure is very large. A typical reflex enclosure may have a longest dimension of three feet or more. Also, due to their size and the cost of large loudspeakers, such systems tend to be very expensive.

To reduce the size and cost, the sealed enclosure is far more commonly used; particularly in stereophonic system where, in general, two loudspeaker systems are used. Since a fully-sealed enclosure prevents any interaction between sound waves produced on both sides of the loudspeaker cone, the system behaves as though the loudspeaker(s) were mounted on an infinitely large baffle irrespective of the size of the enclosure. With modern small enclosures, the resonance frequency is at least twice as high as that of the woofer alone in free space and it is necessary to design the woofer to have specially low resonance frequency to provide partial compensation. Another adverse aspect is that the motion of the cone has to take place against the stiffness of the air and thus the air acts like an additional stiffness added to the cone suspension. Thus the smaller the enclosure, the "stiffer" the suspension and this increases the resonance frequency of the loudspeaker — with consequent loss of bass note clarity. A further disadvantage of the sealed enclosure is that, in addition to increasing the stiffness of the cone — which reduces the output power — radiation from the back of the cone is absorbed by the enclosure. Such systems thus work at low efficiency compared with reflex systems. Thus the sealed enclosure, in its modern commercial form, is a compromise between size (and cost) and the quality of reproduction.

An object of the present invention is the provision of a multi-loudspeaker assembly which has at least some of the advantages of the vented-enclosure system and is yet cheap to manufacture.

According to the invention there is provided a multi-loudspeaker assembly for the reproduction of stereophonic sound from first and second audio frequency stereophonic signal channels; the assembly comprising first, second and third loudspeakers in an elongate housing having a respective vent in or adjacent to each end thereof, the first and second loudspeakers being located nearer to respective ends of the housing than to the centre thereof and the third loudspeaker being so located within the housing that sound waves radiated from the front of the third loudspeaker are transmitted from the housing via one of the two vents and that sound waves radiated from the back of the third loudspeaker are transmitted from the housing via the other vent, means for feeding predominantly signals having a frequency range above a first given frequency in the first and second signal channels to the first and second loudspeakers respectively and for feeding predominantly signals in both channels having frequencies below the first given frequency to the third loudspeaker.

Use is made of the fact that, below a given frequency, the direction of a sound source cannot readily be detected by a listener in a closed space such as a room. It is generally agreed that this given frequency is in the order of 1000 Hz but this depends not only upon the particular listener but also on the configuration and sound-reflecting properties of the room concerned. For a very small room with high reflection from the walls, this given frequency is considerably increased and, for example, in the passenger compartment of an automobile may be as high as 5000 Hz. Thus the signals from both signal channels that have a frequency below the given frequency can be combined in one loudspeaker, via an appropriate filter network, without affecting any binaural effect. The binaural effect is provided by the higher frequency signals of the two channels being respectively radiated by the first and second loudspeakers. By arranging that the third loudspeaker, by virtue of the vents, provides a separate sound signal source adjacent each of the first and second loudspeakers, we have somewhat surprisingly found that the binaural effect is considerably improved — particularly in a small space such as an automobile, where we have found that the given frequency may be as high as 8000 Hz without any substantial reduction in the binaural effect. This gives the further advantage that the first and second loudspeakers may be tweeters (i.e. very small units) and the third loudspeaker may be a squawker if the length of the enclosure is in the region of a few feet since the advantage of the excellent bass reproduction of a vented enclosure is obtained.

We have further found that, although the sound waves radiated from the front and back of the third loudspeaker have approximately equal intensity and are 180° out of phase at the loudspeaker, the effects of standing waves and "dead points" due to mixing the two sound waves are surprisingly not noticeable to a listener in an automobile.

An embodiment of a multi-loudspeaker assembly according to the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 shows a block schematic circuit of an assembly according to the invention,

and

Figure 2 shows, in longitudinal cross section and not to scale, a preferred embodiment of the construction of the loudspeaker assembly of Figure 1.

Referring now to Figure 1, A and B are inputs for the A and B signal channels of an audio frequency stereophonic signal. Input A is connected to a cross-over filter network 1 having a first output 2 at which predominantly the signals appear which have a frequency above a given frequency (the cross-over frequency). For convenience, these signals will be referred to as the higher frequency range signals and signals having frequencies below the cross-over frequency will be referred to as the lower frequency range signals. These lower frequency range signals appear at output 3 of cross-over filter 1.

In a similar manner, input B is connected to a cross-over filter 4, having the same cross-over frequency as filter 1; the upper frequency range signals of a B-channel input signal on input B appearing at output 5 and the lower frequency range signals appearing at output 6. The output signals appearing at outputs 2 and 5 are fed to loudspeakers 7 and 8 respectively, each of which loudspeakers may be a squawker or a tweeter. The outputs at 3 and 6 are combined and fed to loudspeaker 9, which is a woofer. The design of filters 2 and 4 follows conventional practice and needs no further description herein as the design methods and requirements are very well known. Obviously, since the two channels are combined at their lower frequencies for feeding loudspeaker 9, care has to be taken to ensure that there is no mutual interference between the two channels. Although filters 1 and 4 are shown, for clarity purposes, as two separate filters each having two outputs, these filters would normally be combined as a filter network having three outputs.

Loudspeakers 7, 8, 9 are housed in an elongate housing 10 provided with two vents 11 and 12 in opposite ends thereof. Loudspeakers 7 and 8 are housed on a wall 13 of the housing 10 so that they both face in substantially the same direction. Loudspeaker 9 is located within the housing between vents 11 and 12 such that sound waves radiated from the front of the loudspeaker are emitted from the housing via vent 11 and such that sound waves transmitted from the rear of the loudspeaker are emitted from the housing via vent 12. Vents 11 and 12 are respectively located near loudspeakers 7 and 8. Vents 11 and 12 are shown at respective ends of the housing 10 but they may alternatively be located in the wall 13, each vent being near its associated loudspeaker 7 or 8.

Filter network 1-5 may be accommodated external to housing 10 as shown but is preferably located on or within the housing.

Figure 2, which is not to scale, shows schematically a longitudinal cross section of a practical arrangement of a multi-loudspeaker assembly. Items corresponding to those shown in Figure 1 are given corresponding reference numerals. Housing 10 comprises an open-ended tube (of circular, rectangular or other cross section), the open ends of which tube form vents 11 and 12. Housing 10 is provided with apertures 21 and 22 in wall 13, behind which apertures loudspeakers 7 and 8 are respectively located so that sound waves are radiated from the fronts of these loudspeakers in substantially the same general direction as indicated by arrows 23, 24.

Loudspeaker 9 is arranged within the housing 10 so that sound waves emitted by the loudspeaker travel longitudinally of the housing in each direction and are emitted from vents 11 and 12 in the manner indicated by arrows 25, 26. It is to be understood that arrows 23 to 26 are only generally indicative of the major axis of polar radiation pattern for each loudspeaker.

Loudspeaker 9 is located towards one end of the housing 10. The cavity 29 formed between the back of loudspeaker 9 and vent 12 thus forms a tuned acoustic load having the form of a vented enclosure. The bass note response of the system is therefore very considerably better than for the conventional sealed enclosure used for the majority of domestic requirements. In a practical embodiment, the length of cavity 29 was about three feet and the volume of the cavity was a little under a cubic foot. The length of the cavity 29 can be increased, for the same length of housing 10, by locating loudspeaker 9 at the open end of the housing, i.e. at vent 11. The particular arrangement shown was chosen so as to allow access to loudspeaker 7 through the open end of the housing. The distance between the centres of loudspeakers 7 and 8 was a little over three feet, this distance being chosen as a suitable compromise between the length of the housing and the stereophonic effect obtained. A change in this distance of $\pm$ 25% made little difference to the stereophonic effect in an average sized room and it was found that this distance could be reduced to less than two feet when the system was used in a automobile. A corresponding reduction in the length of the housing 10, however, produced a reduction in the bass response of the system.

When used in automobiles, the assembly is located along the rear parcel shelf immediately behind the tops of the rear pass-

enger seats, and listener tests have indicated that the system gives better sound reproduction quality than that given by two separate commercially-available sealed enclosure assemblies, the increase in bass response being quite remarkable. As stated earlier herein, there was no audible interference between the sound waves emitted from vents 11 and 12, this being presumably due to the many short-distance sound-reflecting paths in an automobile. Since the more "direction-sensitive" sound waves from loudspeakers 7 and 8 are directed mainly along the side walls of the automobile, the stereophonic effect was markedly strong irrespective of the position of the listener.

A principle advantage of the assembly when used in an automobile, however, is that it is unobtrusive and does not impede the driver's vision angle through the rear window. This is in sharp contrast to the conventional high quality sound reproduction system which uses two box-like enclosures one at each end of the rear parcel shelf. Also, the assembly according to the invention can be manufactured more cheaply than the conventional system just referred to.

Vents 11, 12 and apertures 21, 22 are preferably covered with a sound-permeable material in order to prevent ingress of dust and moisture and also to improve the appearance of the system.

In one practical embodiment of an assembly of the general type shown in Figure 2, the housing was substantially circular in cross-section and was about four feet long. The end portions of the housing were provided with a larger diameter than the intervening portion; each end portion being about six inches long and five inches in internal diameter, and the intervening portion being about four inches in internal diameter. This not only gave a pleasing appearance but also provided a suitable ledge at the reducing-diameter portion at one end on to which the rim of loudspeaker 9 could be fixed, e.g. by means of an air-setting elastomeric adhesive material. Alternatively, an internal flange such as flange 28 in Figure 2 may be provided to which the loudspeaker 9 may be fixed.

Housing 10 is preferably manufactured in the form of two halves which are subsequently joined along their edges (one edge 29 shown in broken line in Figure 2), for example by glueing, or by means of integral co-operating snap-in devices.

In another embodiment, the housing was a tube provided with a D-shaped cross section, loudspeakers 7 and 8 being located on the flat face forming the straight portion of the "D".

In yet a further embodiment, housing 10 was formed as a tube with a rectangular cross section, this configuration being suited to mounting the system on a wall of a room. In an alternative form of this embodiment, the ends of the tube were closed and a vent was provided adjacent each loudspeaker 7 and 8 in the wall of the housing to which these loudspeakers were fixed.

Although no fixing means are shown in Figure 2 for fixing the assembly to a wall, parcel shelf, etc., these can be any of the well-known types suitable for the particular purpose and form no part of the invention.

As explained previously, the reproduction quality of a multi-loudspeaker assembly can be improved by using three types of loudspeaker, namely a woofer, a squawker, and a tweeter, each predominantly responding to a different audio frequency range. The same, of course, applies to an assembly according to the invention. In a practical embodiment, a housing having similar dimensions to that of the aforedescribed embodiment was used. Loudspeakers 7 and 8 were squawkers and a respective additional tweeter was located adjacent to each squawker in wall 13. A filter network was used which had two cross-over frequencies of 500 Hz and 4500 Hz; these frequencies being decided by the particular loudspeakers used. The low frequency (below 500 Hz) band of both signal channels were combined and fed to loudspeaker 9 (woofer). The mid-frequency (500 Hz to 4500 Hz) band of each signal channel was fed to respective loudspeakers 7 and 8, and the high-frequency (above 4,500 Hz) of each signal channel was fed to the appropriate one of the two tweeters. Different types of loudspeaker would require different cross-over frequencies for optimum reproduction quality, of course, but the lower of the two cross-over frequencies is preferably in the range 300 to 600 Hz and the higher cross-over frequency is in the range 4000 to 6000 Hz.

WHAT WE CLAIM IS:—

1. A multi-loudspeaker assembly for the reproduction of stereophonic sound from first and second audio frequency stereophonic signal channels; the assembly comprising first, second, and third loudspeakers in an elongate housing having a respective vent in or adjacent to each end thereof, the first and second loudspeakers being located nearer to respective ends of the housing than to the centre thereof and the third loudspeaker being so located within the housing that sound waves radiated from the front of the third loudspeaker are transmitted from the housing via one of the two vents and that sound

waves radiated from the back of the third loudspeaker are transmitted from the housing via the other vent, means for feeding predominantly signals having a frequency range above a first given frequency in the first and second signal channels to the first and second loudspeakers respectively and for feeding predominantly signals in both channels having frequencies below the first given frequency to the third loudspeaker.

2. A multi-loudspeaker assembly according to Claim 1 wherein the given frequency lies within the range 400 to 4000 Hz.

3. A multi-loudspeaker assembly according to either previous Claim wherein said means is located in the housing.

4. A multi-loudspeaker assembly according to any previous Claim wherein said means is a cross-over filter network.

5. A multi-loudspeaker assembly according to any previous Claim including a fourth loudspeaker adjacent the first loudspeaker and a fifth loudspeaker adjacent the second loudspeaker, wherein the said means predominantly feeds audio frequency signals in a range between the first given frequency and a second, higher, given frequency to the first and second loudspeakers, and predominantly feeds audio-frequency signals above the second given frequency in the first and second channels to the fourth and fifth loudspeakers respectively.

6. A multi-loudspeaker system according to Claim 5 wherein the second given frequency lies in the range 4000 to 6000 Hz.

7. A multi-loudspeaker assembly according to any previous Claim wherein the housing comprises an open-ended tube the open ends of which constitute said vents.

8. A multi-loudspeaker assembly according to Claim 7 wherein the third loudspeaker is located towards one end of the tube.

9. A multi-loudspeaker assembly according to Claim 7 or 8 wherein the tube has a substantially circular cross section.

10. A multi-loudspeaker assembly according to any of Claims 7 to 9 wherein the end portions of the tube are enlarged compared with the intervening portion.

11. A multi-loudspeaker assembly according to any previous Claim wherein the minimum distance between the centres of the first and second loudspeakers is two feet.

12. A multi-loudspeaker assembly substantially as hereinbefore described with reference to and as shown in the accompanying drawing.

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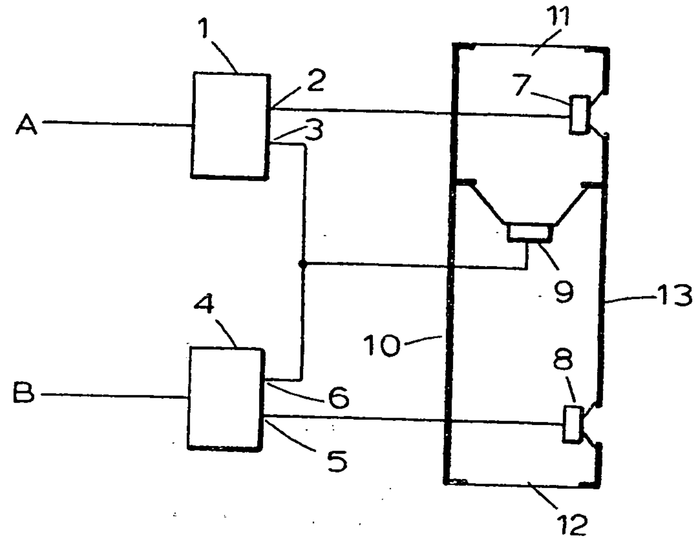

Fig.1.

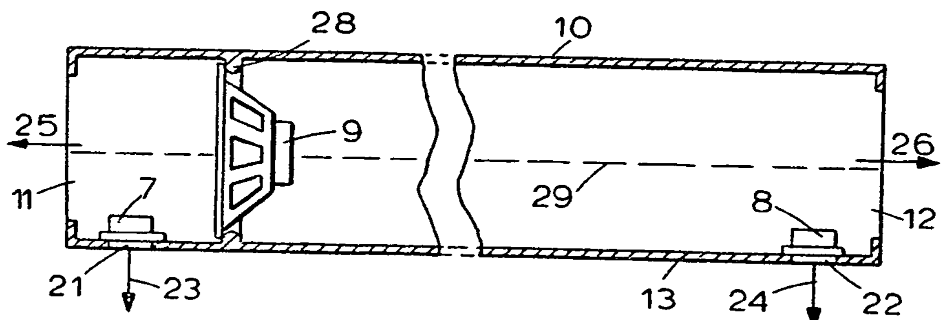

Fig.2.